

SOIL ALGAE OF CRYPTOGAMIC CRUSTS FROM THE UINTAH BASIN, UTAH, U.S.A.

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ABSTRACT.— The algal flora of selected soils in the Uintah Basin, Uintah County, Utah, was studied. A total of 45 species was identified from the top soils of three different vascular plant habitats. The soil algal flora was dominated in biomass by filamentous Cyanophyta, including *Microcoleus vaginatus*, *Phormidium minnesotense*, and three species of *Nostoc*. These algae formed the algal matrix of the soil within which other Cyanophyta as well as Chlorophyta, Bacillariophyta, and Euglenophyta occurred.

Cryptogamic crusts composed primarily of algae, lichens, mosses, and fungi are common in soils of much of western North America (Anderson and Rushforth 1976). Such crusts are one of the most important factors in stabilizing arid soils of this region (Rushforth and Brotherson 1982).

Algal components of cryptogamic crusts are found in the top few millimeters of soil (Hunt and Durrell 1966). Filamentous algae particularly have been shown to be important in binding surface soil particles (Anantani and Marathe 1974, Durrell and Shields 1961). Durrell and Shields (1961) showed that the thick gelatinous sheaths surrounding filaments of some algal species act as organic binding agents in soils even if the algae are dead. Such sheaths hold water (Bailey et al. 1973, Brotherson and Rushforth 1983) and retard desiccation of soils following storms. Kleiner and Harper (1972, 1977) found that crusts stabilize erodible soils and thus add to the long-term stability of desert grasslands.

Soil fertility appears to be increased by cryptogamic crusts (Fletcher and Martin 1948, Shields and Durrell 1964). Nitrogen fixation by cryptogamic crusts on soil surfaces constitutes an important input to many arid land ecosystems (Mayland et al. 1966, Rychert and Skujins 1974, Shields et al. 1957). Algal components also provide the organic resources required for heterotrophic nitrogen fixers as their thalli decompose (Klubek and Skujins 1980).

Cryptogamic soil communities have been observed to be important in the establishment

of higher plant seedlings (Breazeale 1929, Fletcher and Martin 1948). This facilitates vascular plant colonization or regeneration on new or disturbed ecosystems (Nebeker and St. Clair 1980, St. Clair et al. 1984).

All these characteristics of cryptogamic crust communities make them extremely valuable to the soils of arid regions. Because of this, the possible use of soil algae in reclaiming poor soils has been suggested by several researchers. For instance, Lewin (1977) presented the results of several experiments that demonstrated that soil algae increased binding of the soil, elevated water retention, and increased levels of soil nitrogen. In view of these results, Lewin discussed the possibility of using algae as commercial soil reclamation agents. Likewise, other researchers have suggested the use of soil algae in land reclamation (Ali and Sandu 1972, MacKenzie and Pearson 1979, Singh 1950). Starks and Shubert (1978, 1982, Shubert and Starks 1979, 1980) studied soils of strip-mined lands and showed that significant stabilization of such land could be attributed to algae.

A knowledge of the component organisms of cryptogamic crusts and their usefulness in soil stabilization, enhanced fertility, and reclamation is particularly important in western North America. Serious reclamation problems in fragile arid ecosystems will occur following ecosystem and soil disturbance due to proposed oil shale mining and processing. This paper is companion to another that discussed the establishment and growth of soil algae on processed oil shale (Ashley and Rush-

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forth 1984). The purpose of the present paper is to identify all algal species found in cryptogam crusts of selected undisturbed sites of the Uintah Basin, Utah.

SITE DESCRIPTION

The Uintah Basin is a topographic depression ranging between 1500 and 1800 m in elevation located in northeastern Utah and northwestern Colorado. During Tertiary times the basin was the site of several large freshwater lakes, within which were deposited extensive lacustrine sediments, including the oil-shale-bearing Green River Formation. Much of the central portion of the Uintah Basin is desertic, with annual precipitation less than 24 cm. Summer rains make up about half of the total precipitation and occur mostly as thunderstorms that are generally short lived but of high intensity. Snow averages about 75 cm per year and melts quite slowly, allowing water to saturate the soils. Soil erosion in the study area, mostly due to violent summer storms, has been classified as critical (Wilson et al. 1975).

METHODS

Cryptogam crusts were sampled from soils at six localities in the three dominant vascular plant communities (pinyon-juniper, shadscale, and greasewood) of the regions in the Uintah Basin to be impacted directly by oil shale development. Samples were placed in sterilized plastic bags and returned to our laboratory for analysis.

A portion of each crust sample was placed in a sterilized petri dish with 15 ml of distilled water for culturing to allow identification of algal species. Most crust subsamples showed algal growth after two days. Even so, we did not begin identification until after two weeks of growth under continuous light to insure encountering the maximum number of species.

Nondiatom algae were identified by direct microscopical examination of wet mounts. Permanent diatom slides were made by boiling diatoms in concentrated nitric acid following standard procedures (St. Clair and Rushforth 1976). All organisms were studied and

photographed using Zeiss RA microscopes with Nomarski, bright field, and phase contrast optics.

RESULTS AND DISCUSSION

Soil algal floras tend to show high similarity throughout wide geographic regions. For instance, all the soil floras we have examined in western North America contain a common suite of species, are dominated by blue-green algae, show a paucity of green algae, and have relatively diverse diatom floras. The Uintah Basin flora is no exception. Of the 45 alga taxa identified from our crust samples, 16 were blue-green algae (Cyanophyta), 4 were green algae (Chlorophyta), 24 were diatoms (Bacillariophyta), and 1 was *Euglena gracilis*. The most abundant species in our samples were all filamentous Cyanophyta, especially *Microcoleus vaginatus*, *Phormidium minnesotense*, and *Nostoc commune*. *Microcoleus vaginatus* was most important in binding the soil and producing the initial crust. The importance of *Microcoleus* has been observed in many localities in arid soils of western North America (Anderson and Rushforth 1976).

Even though the Uintah Basin algal flora shows strong similarities to other floras of western North America, it contains several new distribution records. The following taxa have not previously been reported from Utah soils: *Achnanthes exigua*, *Calothrix parietina*, *Chroococcus hansgiri*, *Gomphonema parvulum*, *Navicula asellus*, *Navicula cryptocephaloides*, *Navicula minima*, *Navicula paramutica*, *Navicula tenelloides*, *Nitzschia communis*, *Nitzschia hantzschiana*, *Nitzschia inconspicua*, *Palmella miniata*, *Scytonema hofmanni*, and *Stigonema hormoides*. Two of these, *Chroococcus hansgiri* and *Navicula asellus*, also represent new records for the state of Utah.

The algal species identified in our samples are described briefly in the following section. In addition, each is illustrated in the drawings and/or photographs composing the accompanying plates.

DIVISION CYANOPHYTA

Anabaena cf. *variabilis* Kuetz. (Fig. 10). Plants filamentous; cells 2-4 μ m long, 4-6

μm wide, irregular barrel shaped; heterocysts and akinetes not observed. Since we did not observe akinetes or heterocysts, the placement of our specimens into this taxon remains tentative. However, we have seen this species in nearly all of the soil samples we have previously examined from the Great Basin and Colorado Plateau.

Calothrix parietina (Naeg.) Thuret (Fig. 11). Plants filamentous, brown to almost black; trichomes 5–9 μm wide, tapering, sometimes to a hair; cells granular, subquadrate to quadrate, 3–6 μm long by 5–8 μm wide; heterocyst basal, hemispherical, 6–10 μm wide; sheaths hyaline, not lamellate. *Calothrix* species are occasionally reported from moist soils, and we have often collected them from wet walls in western North America. However, this is the first time we have found *Calothrix* in the soils of our area.

Calothrix species (Fig. 12). Plants filamentous, yellowish to brown; filaments 3.5–5 μm wide; short and stubby, but similar to *Calothrix parietina*; cells 1–4 μm long.

Chroococcus hansgiri Schmidle (Fig. 1). Plants unicellular or in small clusters, often aggregated into irregular masses; cells reddish, 8.5–10.5 μm in diameter. This is the first report of this taxon from Utah soils.

Chroococcus turgidus (Kuetz.) Naegeli (Fig. 2). Plants unicellular or spherical colonies; colonies 9–25 μm in diameter, containing 2–3 cells, occasionally more; colonial sheaths hyaline, slightly lamellate, 1 μm thick; cells ovoid if single, usually hemispherical if colonial, 4–10 μm in diameter. Our specimens of *C. turgidus* were somewhat smaller than those collected from aquatic habitats. However, we have observed this commonly with this taxon (Anderson and Rushforth 1976, Johansen et al. 1981).

Lyngbya limnetica Lemm. (Fig. 6). Plants filamentous; trichomes 2–2.5 μm wide, straight, not constricted at cross walls, not tapering; cells 6–11 μm long, pale grey-green, not granular; sheaths firm, colorless, thin. This species is commonly observed in the soils of the Great Basin.

Microcoleus vaginatus (Vauch.) Gom. (Figs. 7–8). Plant filamentous with evident sheath, one to many trichomes within sheath; cells 2.5–6 μm wide, quadrate or longer than broad, crosswalls not constricted; terminal

cell attenuated, rounded or capitate, with or without calyptres. *M. vaginatus* was the most abundant species in our samples. This taxon usually dominates the soil algal floras in the Intermountain West. It is often the primary constituent of algal mats and cryptogam crusts, and has been reported as being important in stabilizing desert soils (Anderson and Rushforth 1976, Rushforth and Brotherson 1983).

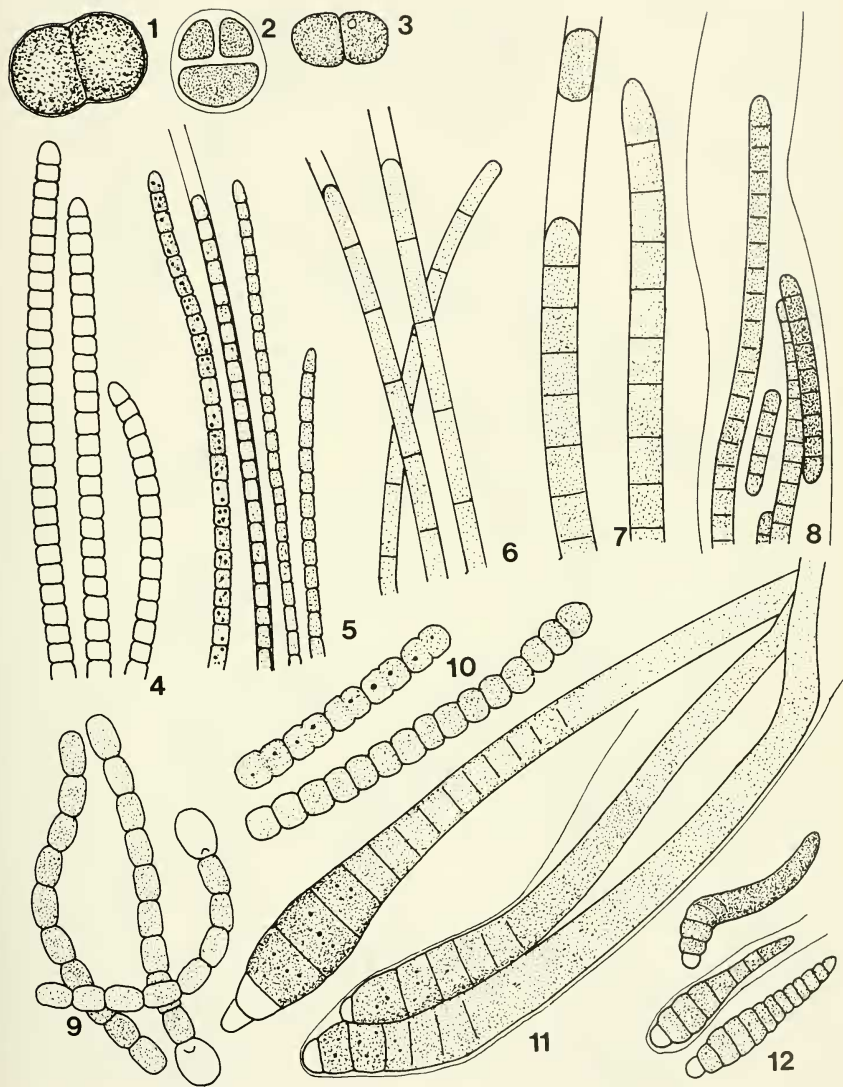
Nostoc commune Vaucher (Fig. 9). Plants cream colored to olive green, globular, firm, with age becoming lobed and clathrate; trichomes closely entangled and intertwined; cells subglobose or barrel shaped, 4–6 μm long by 3.5–4 μm wide; heterocysts frequently spherical, 5–6 μm in diameter. Several species of *Nostoc* are important in the soil algal floras of the Great Basin and Colorado Plateau. *Nostoc* is often very important in soil biology because of nitrogen fixation and soil binding.

Nostoc muscorum Agardh (Figs. 13–14). Plants yellow to brown, individual trichomes ensheathed; cells globose to elliptical, 3–4 μm in diameter by 4.5–6 μm long; heterocysts globose, singular, 4.5 μm in diameter by 5–7 μm long. This taxon is very similar to *N. commune*, differing primarily in having smaller cell size and oblong heterocysts.

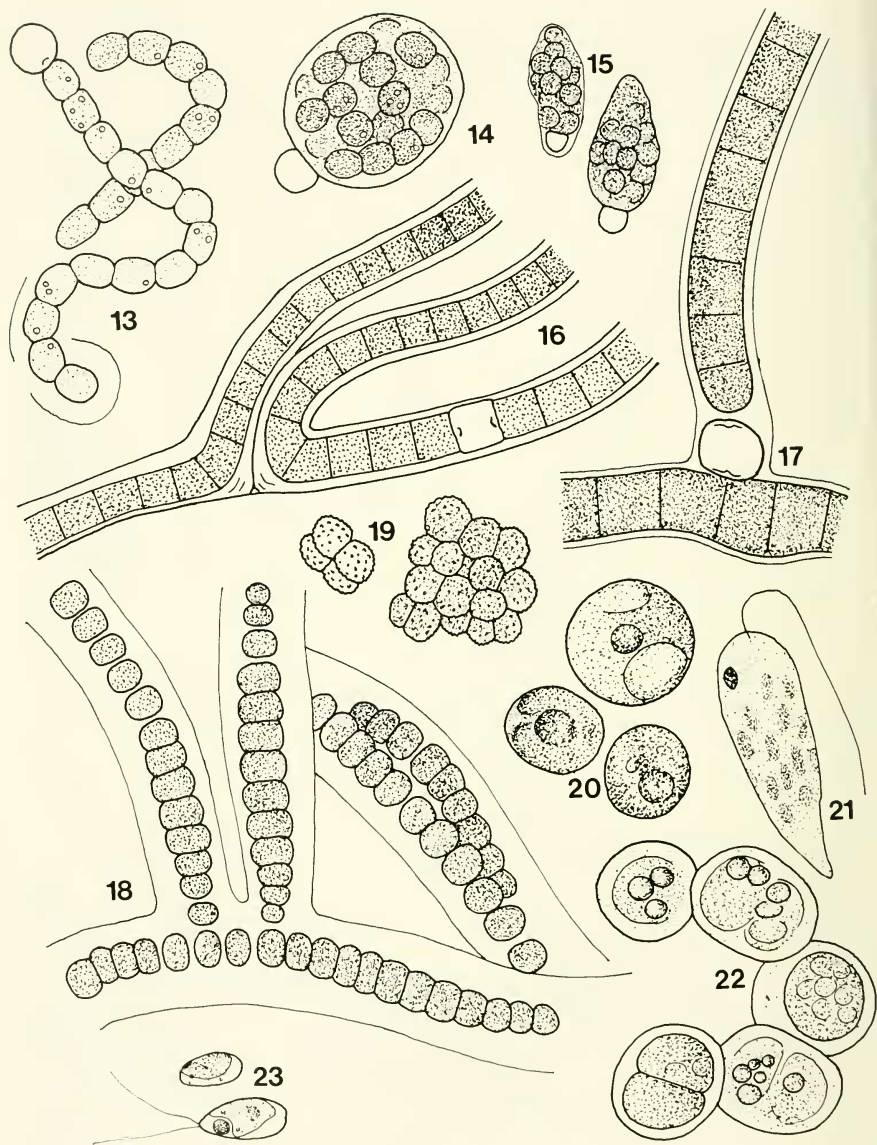
Nostoc punctiforme (Kuetz.) Hariot (Fig. 15). Plants small, blue-green colonies with firm sheath and indistinct trichomes; cells globose, 2–4 μm in diameter; heterocysts apical, spherical, often flattened at point of attachment, 2.5–3.5 μm in diameter. This *Nostoc* has smaller cells than either *N. commune* or *N. muscorum*. Our specimens were similar to those described by Desikachary (1959).

Oscillatoria tenuis Agardh (Fig. 4). Plant filamentous; sheaths absent; trichomes 2–3 μm wide, straight or slightly flexuous in apical portion, not tapering, constricted at crosswalls; apical cells convex, smooth, not capitate; cells 2–3 μm wide, slightly broader than long; cell contents granular. This *Oscillatoria* is commonly seen in the soils of our area. It is generally present in small numbers.

Phormidium minnesotense (Tilden) Drouet (Fig. 5). Plant filamentous; trichomes 2–3 μm wide, slightly curved, constricted at crosswalls, not tapering; cells 2–3 μm long by 1.5–2 μm wide; apical cell rotund; cell contents homogenous, gas vacuoles often present. This



Figs. 1-12: 1, *Chroococcus hansgiri*; 2, *Chroococcus turgidus*; 3, *Synechococcus aeruginosus*; 4, *Oscillatoria tenuis*; 5, *Phormidium minnesotense*; 6, *Lyngbya limnetica*; 7-8, *Microcoleus vaginatus*; 9, *Nostoc commune*; 10, *Anabaena cf. variabilis*; 11, *Calothrix parietina*; 12, *Calothrix* species. All figures are X1000.



Figs. 13-23: 13-14, *Nostoc muscorum*; 15, *Nostoc punctiforme*; 16, *Scytonema hofmanni*; 17, *Tolypothrix tenuis*; 18, *Stigonema hormoides*; 19, *Chlorosarcina* cf. *brevispinosa*; 20, *Chlorococcum* cf. *humicola*; 21, *Euglena gracilis*; 22, *Palmella miniata*; 23, *Chlamydomonas* species. All figures are X1000.

Phormidium is important in crust formation in many of the arid soils of our region.

Scytonema hofmanni Agardh (Fig. 16). Plant mass caespitose to floccose, dark blue-green to blackish; trichomes 7–8 μm wide forming upright fascicles; false branches rare, single or in pairs; sheaths firm, thin to thick; cells 2–5 μm long, 4–7 μm wide; heterocysts cylindrical, rounded at the ends; cell contents homogeneous. *Scytonema* is occasionally observed on the soil. However, we have not collected this species previously.

Stigonema hormoides (Kuetz.) Born. and Flah. (Fig. 18). Basal filaments long, decumbent, uniseriate, rarely biseriate in places, densely matted, forming a thin, felty, brownish plant mass; filaments 10–20 μm wide, sparsely and irregularly branched, side branches about as broad as main filaments; sheaths thick, colorless; cells spherical to compressed ovoid, 2.5–5 μm wide. This *Stigonema* was important in forming crusts in our samples. It was characterized by dark-colored cells and superficially resembled *Calothrix* species. It differed from *Calothrix* in the presence of true branched filaments.

Synechococcus aeruginosus Naegeli (Fig. 3). Plant unicellular or bicellular, occasionally with 4 cells; cells ovoid to cylindrical, 6–16 μm long by 6–8 μm wide; cellular contents granular, greyish. This organism is generally aquatic, but we have observed it from soils in the Uintah Basin and Tintic Mountains of Utah.

Tolypothrix tenuis Kuetz. (Fig. 17). Plant mass caespitose to floccose, blue-green to brownish; filaments 5–12 μm wide; false branches single, uncommon; sheaths membranaceous, thin, colorless or yellowish, somewhat inflated at the bases; trichomes 5–8 μm wide, slightly or not constricted at cross walls; cells equal to or longer than broad; cell contents blue-green to olive; heterocysts single or double, rounded, colorless. This taxon has been observed in other Utah soils. It is characterized by its yellowish color and rare false branching.

DIVISION CHLOROPHYTA

Chlamydomonas sp. (Fig. 23). Cells 7–10 μm long by 3–5 μm wide, biflagellate; pyrenoids one to several. This species was very rare in our samples.

Chlorococcum cf. *humicola* (Naeg.) Rabh. (Fig. 20). Cells spherical or rarely ellipsoidal, solitary or in small aggregates, granular, bright green, 9–16 μm in diameter; chloroplast covering most of the cell wall. Chlorophyta were not common in our Uintah Basin soils. This is not surprising since it has been reported that alkaline soils are poor in green algae (Metting 1981). Due to the paucity of specimens, it was not possible for us to confirm species assignment. *Chlorococcum* spp. are separated from *Chlorosarcina* spp. by the absence of cell packets. We did not observe sexual phases in any of our coccoid green algae.

Chlorosarcina cf. *brevispinosa* Chant. and Bold (Fig. 19). cells spherical to ovoid, in colonies of 2–4, often forming dense irregular families; enclosed by wide, lamellate sheath; cells 2.5–5 μm in diameter.

Palmella miniata Leiblein (Fig. 22). Plants unicellular or aggregated into loose groups of 2–7 cells; cells spherical to ovoid, 10–14 μm long by 9–17 μm wide, imbedded in copious mucilage; starch grains abundant. This alga occasionally formed reddish colored patches on our soils after several weeks of culturing. We have collected this taxon from other sub-aerial habitats, but it appears to be more abundant on wet walls than in soils.

DIVISION EUGLENOPHYTA

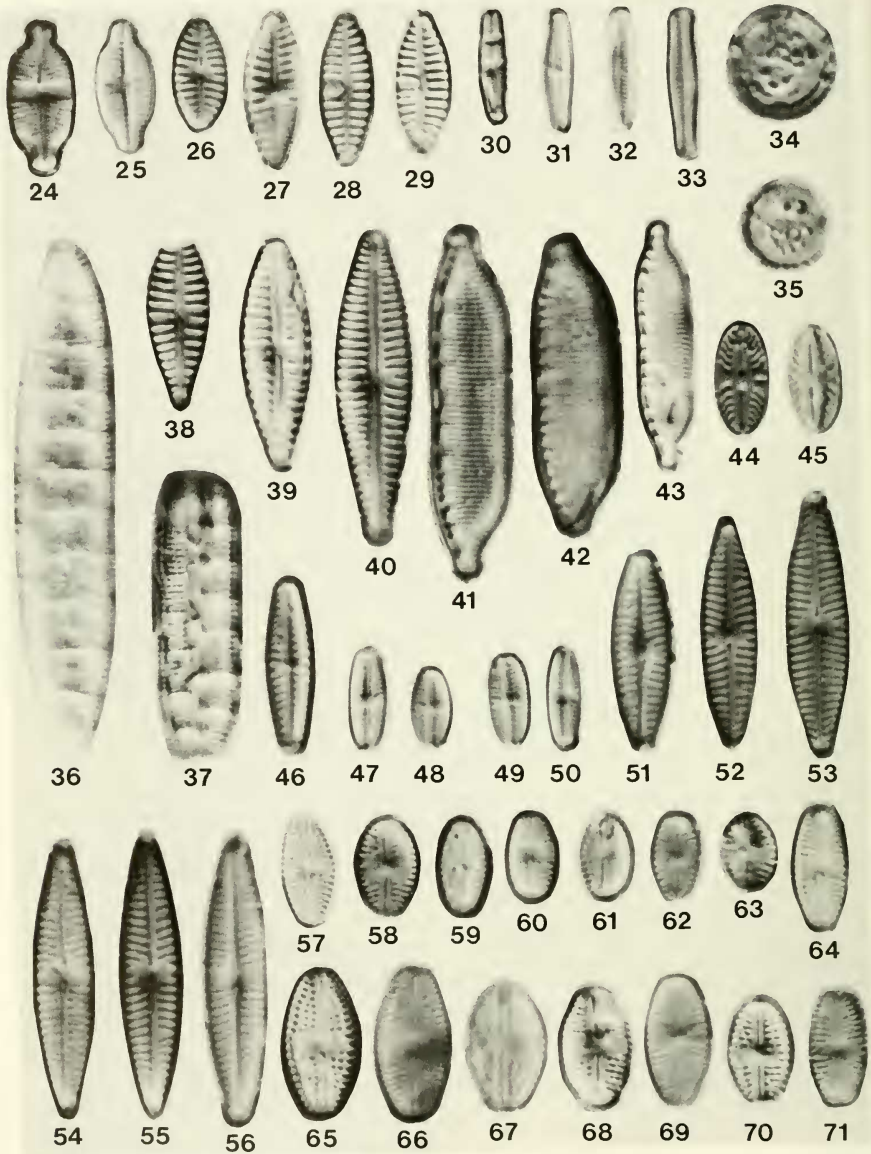
Euglena gracilis Klebs (Fig. 21). Cells active, elliptical, rounded anteriorly, tapering posteriorly, 30 μm long by 10 μm wide. We saw only a few specimens of this *Euglena* after culturing.

DIVISION BACILLARIOPHYTA

Achnanthes exigua Grun. (Figs. 24–25). Valves 11–13 μm long by 5–6 μm wide; striae on both valves 20–23 in 10 μm , finer towards ends. *Achnanthes exigua* has not previously been reported from the soils of our area.

Achnanthes lanceolata (Breb.) Grunow (Figs. 26–29). Valves 7–14 μm by 4.5–6 μm wide; striae slightly radiate, 11–15 in 10 μm on both valves. This taxon is rare in Utah soils.

Achnanthes linearis (W. Smith) Grunow (Figs. 30–33). Valves 9–13 μm long by 2–3 μm wide; striae on both valves 24 in 10 μm in the



Figs. 24-71: 24-25, *Achnanthes exigua*; 26-29, *Achnanthes lanceolata*; 30-33, *Achnanthes linearis*; 34-35, *Cyclotella kuetzingiana* var. *planetophora*; 36-37, *Denticula elegans* f. *valida*; 38-40, *Gomphonema parvulum*; 41-43, *Hantzschia amphioxys*; 44-45, *Navicula asellus*; 46, *Navicula tenelloides*; 47-50, *Navicula minima*; 51-56, *Navicula cryptocephaloides*; 57-71, *Navicula mutica* var. *cohnii*. All figures are X2000.

center becoming about 30 near the ends. *A. linearis* is the most common *Achnanthes* in soils of cold deserts of western North America.

Cyclotella kutzingiana var. *planetophora* Fricke (Figs. 34–35). Valves 8–17 μm in diameter; striae marginal, 20–22 in 10 μm . This species has been observed in several localities in Utah. Most of our specimens are eroded, and we have never observed living cells. This taxon, *Cyclotella bodanica* and *Stephanodiscus carconensis* are the only centric diatoms to regularly occur in soils of our region.

Denticula elegans f. *valida* Pedic. (Figs. 36–37). Valves 20–44 μm long by 5–8 μm wide; costae 3–4 in 10 μm ; alveoli rows 19–21 in 10 μm . This taxon appears to be a thermophile in the Great Basin and Colorado Plateau. We have often collected it in thermal springs, drip walls with high insolation, and soils.

Diploneis sp. Valves 73 μm long by 20 μm wide; costae 9–10 in 10 μm . Only fragments of this *Diploneis* were observed. Our specimens may belong to *Diploneis smithii* that has been observed in southern Utah soils (Anderson and Rushforth 1976).

Epithemia turgida Kuetz. Valves 67–92 μm long by 12–14 μm wide; costae 2–4 in 10 μm ; alveoli rows 10 in 10 μm ; 2–4 alveoli rows between costae. This *Epithemia* occurs in small numbers but consistently in the soils of Utah we have studied. It is generally observed as broken valves.

Gomphonema parvulum Kuetz. (Figs. 38–40). Valves 16–26 μm long by 5–6.5 μm wide; striae 12–15 in 10 μm . *Gomphonema* species are rare in the soils of our region. The only specimens we have observed have been associated with well-developed cryptogamic crusts.

Hantzschia amphioxys (Ehr.) Grunow (Figs. 41–43). Valves 20–32 μm long by 5–7.5 μm wide; fibulae 4–9 in 10 μm ; striae 19–26 in 10 μm . This species is the most abundant diatom in soils of our area and perhaps of the world.

Navicula asellus Krasske (Figs. 44–45). Valves 9–10 μm long by 4–5 μm wide; striae 16–18 in 10 μm . This is the first record of this taxon in western soils. It is also the first record of occurrence of this species in Utah. It is

similar to *N. excelsa*, which has been observed in soils of central Utah.

Navicula crytocephaloides Hust. (Figs. 51–56). Valves 16.5–25 μm long by 4.5–5.5 μm wide; striae 13–14 in 10 μm at midvalve, becoming 16–18 in 10 μm at ends. Our specimens were very closely related to *N. crytocephala* var. *lancettula*, differing primarily in the characteristics of the central area.

Navicula minima Grunow (Figs. 47–50). Valves 7–9 μm long by 3–4 μm wide; striae 28 in 10 μm at midvalve becoming 30–34 in 10 μm near ends. This species was common in soils of the Uintah Basin. It has not been observed in our other soil studies.

Navicula mutica Kuetz. (Figs. 72–85). Valves 12–28 μm long by 5–8 μm wide; striae 18–20 in 10 μm . This is a very common soil diatom, occurring in all soils of our area. Several varieties of this taxon occur in soils. The nominate and *N. mutica* var. *cohnii* are most common. *N. mutica* var. *nivalis*, a common species in Utah soils, was conspicuously absent from our samples from the Uintah Basin.

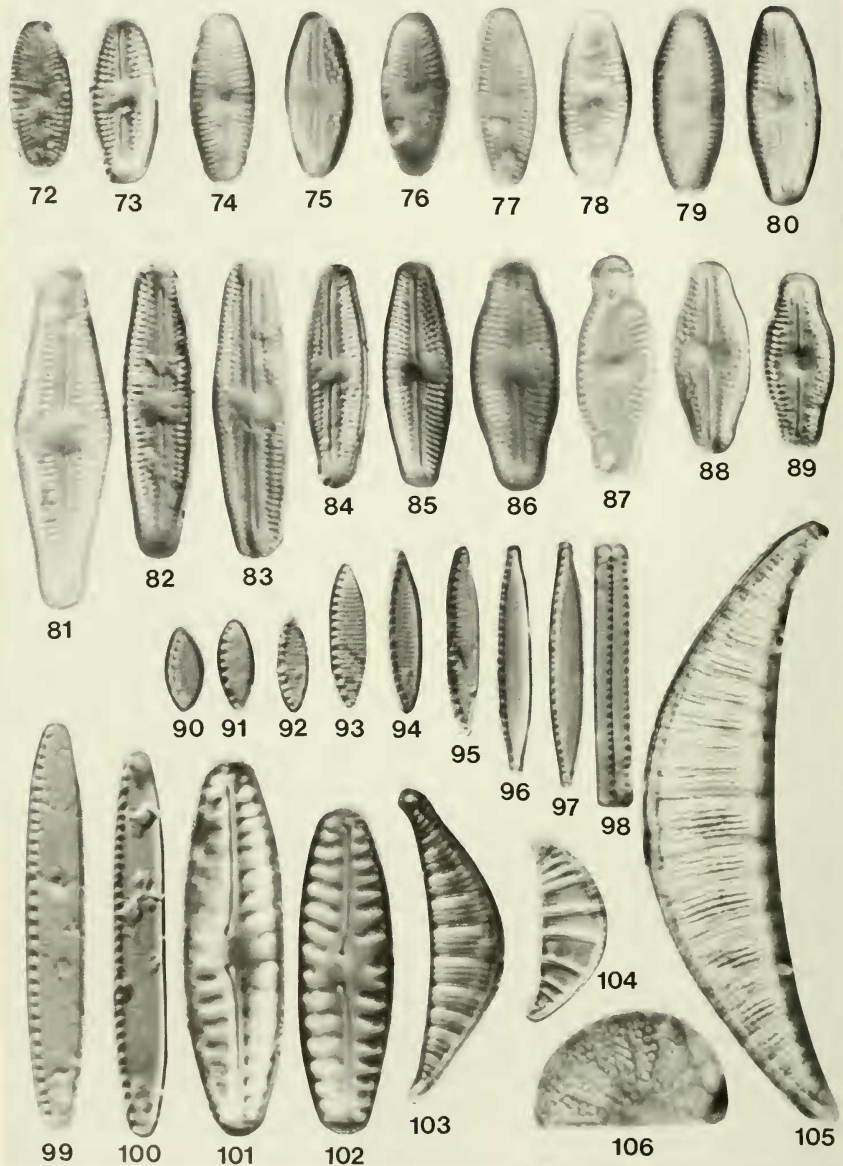
Navicula mutica var. *cohnii* (Hilse) Grunow (Figs. 57–71). Valves 6.5–13 μm long by 4.5–6.5 μm wide; striae 16–22 in 10 μm . Several of our specimens were quite close to *N. imbricata* (Figs. 57–63). However, we placed them into *N. mutica* var. *cohnii* because of the presence of transitional forms between the two and because the majority of our specimens fit the latter very well (Figs. 64–71).

Navicula paramutica Bock (Figs. 86–89). Valves 14–19 μm long by 6–7.5 μm wide; striae 18–20 in 10 μm . This species is similar to *N. mutica*, differing by the presence of attenuated ends.

Navicula tenelloides Hust. (Fig. 46). Valves 15 μm long by 4 μm wide; striae 15 in 10 μm at midvalve, becoming 18 in 10 μm near ends. This taxon is common in the aquatic systems of our area but has not been previously reported from Utah soils.

Nitzschia communis Rabh. (Figs. 99–100). Valves 31–34 μm long by 4.5–5 μm wide; fibulae 9–12 in 10 μm ; striae 32–36 in 10 μm . This is the first report of this taxon from Utah soils.

Nitzschia hantzschiana Rabh. (Figs. 93–95). Valves 12–16 μm long by 2.5–3 μm wide; fibulae 12–14 in 10 μm ; striae 26–27 in



Figs. 72-106. 72-85, *Navicula mutica*; 86-89, *Navicula paramutica*; 90-92, *Navicula inconspicua*; 93-95, *Nitzschia hantzschiana*; 96-98, *Nitzschia palea*; 99-100, *Nitzschia communis*; 101-102, *Pinnularia borealis*; 103-105, *Rhopalodia gibberula* var. *vanheurckii*; 106, *Stephanodiscus carconensis*. All figures are X2000.

10 μm . This species was rare in our samples and has not been observed previously in the soils of our area.

Nitzschia inconspicua Grunow (Figs. 90–92). Valves 7–8 μm long by 2.7–3.5 μm wide; fibulae 12–14 in 10 μm ; striae 28–30 in 10 μm . This taxon has not been reported previously from soils of the Great Basin and Colorado Plateau.

Nitzschia palca (Kuetz.) W. Smith (Figs. 96–98). Valves 17–22 μm long by 2.5–3 μm wide; fibulae 12–16 in 10 μm ; striae unresolved. This taxon has occasionally been found in soils throughout the West. It was rare in samples from the Uintah Basin.

Pinnularia borealis Ehr. (Figs. 101–102). Valves 26–31 μm long by 7–8.5 μm wide; striae 5–6 in 10 μm . This taxon is a common constituent of soils worldwide. It was one of the most common diatoms observed in this study, ranking third in importance behind *Hantzschia amphioxys* and the *Navicula mutica* complex. Many of our valves have the rectangular outline typical of *P. borealis* var. *rectangularis* but did not have the coarser striae characteristic of that variety.

Rhopalodia gibba (Ehr.) O. Mueller. Valve 55 μm long by 16 μm wide; costae 8 in 10 μm ; alveoli rows 14 in 10 μm . Only a single specimen of this taxon was observed in our samples.

Rhopalodia gibberula var. *vanheurckii* O. Mueller (Figs. 103–105). Valves 15–49 μm long by 5.5–11 μm wide; costae 4–7 in 10 μm ; alveoli rows 16–20 in 10 μm . We have observed this taxon in other soils of Utah where it is as rare a species as it is here. The samples from the Uintah Basin contained some very small specimens that were well below the minimum size recorded by other authors. The larger specimens (Fig. 105) are transitional between *R. gibberula* var. *vanheurckii* and the nominate variety.

Stephanodiscus carconensis (Eulens.) Grunow (Fig. 106). Valve 16 μm in diameter; costae 3 in 10 μm ; aerolae forming 4 rows between costae, 12 in 10 μm . This species is widely distributed in the soils of Utah and Arizona, though it is always present in low numbers (Johansen et al. 1981, 1984). It has occasionally been reported as *S. astraea* var. *minutula* (Anderson and Rushforth 1976).

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